

HEADS OF LECTURES,

27.

ON THE

E L E M E N T S

OF

NATURAL PHILOSOPHY,

DELIVERED IN THE UNIVERSITY

OF

ST ANDREWS.



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H E A D S
O F
L E C T U R E S



NNATURAL Philosophy, the science defined—Its uses—Contemplates all the material objects which Nature presents—These objects are very numerous and various; and hence the science is very extensive.

Little progress was made in this science by the antiquits, chiefly because of the improper manner in which they conducted their investigations—Examples in proof of this assertion.

The true method of conducting philosophical investigations.

Rules of Philosophising.

- 1st, Not to indulge in conjectures.
- 2^d, Not to admit the existence of more causes than are sufficient to explain the phenomena and the effects produced.

3^d,

3d, To ascribe similar effects to the same cause.

4th, Those qualities, which in the same body can neither be increased nor diminished, and which belong to all bodies subject to our examination or within the sphere of our observation, are to be accounted the universal properties of all bodies.

On this last rule is founded the method of arguing by induction—The excellency of this mode of arguing—Errors in the management of it—Directions how these errors are to be avoided.

The first business of Natural Philosophy is the contemplation of natural objects—These being very numerous, philosophers were induced to arrange them into classes and orders.

Hence arose systems.

The system of the elements; its beauty and defects.

Material System.

Matter fundamentally the same in all bodies—The diversity of bodies arises from the different modification, arrangement, and mode of cohesion of the particles of matter composing those bodies.

Matter

Matter is whatever has extension and makes resistance.

Various Properties of Matter.

1st, Divisibility without end—This property admitted with difficulty on account of the finite understanding of man—Objected to by metaphysicians—Their objections refuted—The great divisibility of matter observable in various natural objects and operations—It can be carried to great extent by human art—Examples.

2d, Attraction—Of this there are various kinds.

a. Attraction of cohesion, which acts at small and imperceptible distances—Strongest when the particles of matter are similar—Many particles of matter held together by the attraction of cohesion compose a body—Hence the definition of a body—Density of a body—Density proportional to the quantity of matter in the body.

b. Attraction of gravitation—Equally strong between particles of matter that are dissimilar—Acts at all distances—Its force decreases as the square of the distance increases. Hence gravitation

3 HEADS OF LECTURES, &c.

vitation \div square of the distance reciprocally—The cause of bodies falling to the earth, that is, of bodies being heavy—Gravity synonymous with weight—Difference between gravity and gravitation—Weight the measure of gravitation—Hence $G \div W \div Q \div D$. Also $W \div B$; and universally $W \div DB$, and $G \div DB$. Specific gravity the same with density—The gravitation of all the different particles of matter composing a body seems to be concentrated in a certain point within the body, called the *center of gravity*—When this center of gravity is supported, the body is at rest—Equilibrium—Center of suspension and center of gravity always in the same perpendicular line—Stable or permanent equilibrium, and unstable or tottering equilibrium.

c. Peculiar attractions.

d. Elective attractions—These two will be explained and treated of in the sequel.

3d, Inactivity, called also *inertia*.

4th, Mobility, when acted on by any force or power.

Motion, a continual and successive change of place—All motion the effect of some force or power—

power—The force producing motion may be either a momentary impulse, or a constantly acting force.

No motion can be instantaneous, that is, a body in motion requires a certain time to pass over a certain space.

The space passed over by a moving body is a line described by the center of gravity of that moving body—The direction of this line is the direction of the motion ; and it is always in the direction of the force.

Velocity is the rate at which the body moves ; and it may be either uniform, or accelerated, or retarded, or unequable.

Impediment is any thing which either obstructs, resists, diminishes, or destroys motion.

All motion \doteq the force which produced or produces the motion.

Action and reaction equal and contrary.

In considering the circumstances of a body in motion, where the space described is not long, and is near the surface of the earth, we may, without producing any sensible error in our conclusions, suppose that,

1st, A small portion of the earth's surface is a plane.

2^d, All bodies descend, or fall to the earth's surface, in lines parallel to each other.

3^d, The same body is of the same weight at different heights from the earth's surface.

Simple motion is that which is produced by a single force.

Compound motion is that which is produced by two or more forces acting conjunctly at the same time.

Simple motion produced by a momentary impulse is uniform.

Supposing, F = the force producing the motion, v = velocity, t = time spent during the motion, s = the space passed over, Q = the quantity of matter in the body ; in uniform motion we have the following general propositions :

1. $v \doteq F$, when the quantity of matter in the moving body is given.

2. $s \doteq t$, when the velocity is given.

3. $s \doteq v$, when the time is given.

4. $s \doteq tv$.

5. $F \doteq Qv$, when the velocity is given.

6. $F \doteq Qv$.

A body in motion exerts a force against any impediment, which force exerted by the moving body is called the momentum of the moving body; and this momentum is always $\div F$.

Hence momentum $\div Qv$.

Simple motion produced by a constantly acting force is accelerated.

In accelerated motion we have the following propositions, using the same symbols as before, and taking m = momentum

$$1. m \div Ft.$$

$$2. Ft \div Qv.$$

$$3. Qs \div Ft^2.$$

$$4. Fs \div Qv^2.$$

In any particular case where any of these quantities are constant, they may be left out of the proportions; as in the case of falling bodies, where the quantity of matter in the falling body remains the same, and where the force of gravitation near the surface of the earth is the same, Q and F being left out, the propositions will be,

$$1. m \div t.$$

$$2. t \div v.$$

$$3. s \div t^2.$$

$$4. s \div v^2.$$

Compound

Compound motion is the result of two or more forces acting conjunctly upon a body: Of this there are numerous varieties.

1/2, When the body is acted on by two forces which are momentary impulses, the two forces may be either,

- a. In the same direction—In this case the body moves in the direction of the forces; and its velocity \doteq sum of the forces.
- b. In opposite directions—The motion is in the direction of the greater force; and velocity \doteq difference of the forces—If the two forces be equal, the body is kept at rest.
- c. The one oblique to the other—In this case if the directions and the forces be represented by two straight lines AB and AC, and the parallelogram ABDC be formed, the direction of the motion is the diagonal AD, and the body will move through the diagonal in the same time that the body would have passed over AB or AC if acted on by one of the forces separately.

Of the composition and resolution of forces.

If a body be kept at rest by three forces acting conjunctly,

conjunction, the forces are \propto the sides of a triangle formed by lines drawn parallel to the directions of the three forces respectively—Also each force respectively proportional to the sine of the angle made by the directions of the other two—Also \propto sides of a triangle formed by lines drawn perpendicular to the directions of the three forces respectively.

If a body strikes or acts against a plane surface, it exerts its force on the plane in a direction perpendicular to the plane; and the force exerted on the plane \propto sine of the angle of inclination.

If the body be reflected after the stroke, the angle of reflection equals the angle of inclination.

The three foregoing dynamical propositions exemplified by bodies at rest on inclined planes.

If a body be held at rest on an inclined plane by a power hanging freely, and both be set a moving, their perpendicular velocities are reciprocally \propto quantities of matter.

If a body fall down an inclined plane, the velocity acquired by the body in any time : the velocity acquired by a body falling perpendicularly in the same time :: CB : CA—Also \propto sine of the plane's inclination to the horizon : radius.

The

The space described by a body on an inclined plane : space described by a body falling perpendicularly in the same time :: CB : CA.

While a body falls perpendicularly through CB, another will descend along the plane from C to D.

The spaces described on the same plane \div squares of the times.

The time on the plane CA : time of falling perpendicularly through CB :: CA : CB.

The times on different planes of the same inclination \div lengths of the planes.

The times in several successive planes equals the time in one plane of the same height.

The time in a curve equals the time in a plane of the same height.

The velocity acquired by a body moving down a curve \div square root of the height fallen from.

The times of descending through similar parts of similar and similarly situated curves \div square roots of the lengths of the curves.

The times in all chords and in the perpendicular diameter of a circle are equal.

Of Pendulums.

1st, If a pendulum vibrate in a very small arc,

arc, the time of one vibration : time of a body falling perpendicularly through half the length of the pendulum :: circumference : diameter of a circle; that is, :: 3.1416 : 1.

Hence we learn that a body, falling to the earth, falls through 16 feet 1 inch in the first second of its fall. We may therefore take 16 feet 1 inch to represent the force of gravitation at the earth's surface, viz. $G \doteq 193$ inches.

2d, The lengths of pendulums vibrating in similar arcs, \doteq squares of the times of vibration.

3d, The lengths of pendulums vibrating in similar arcs, and in the same time, \doteq forces of gravitation.

4th, The times of vibration of pendulums of the same length vibrating in similar arcs \doteq square roots of the forces of gravitation; and also reciprocally \doteq distances from the center of the earth.

Uses of pendulums; for measuring time; for measuring heights; for ascertaining the figure of the earth.

Every part of a pendulum has a momentum peculiar to itself; and one certain part of the pendulum has a momentum that is the mean of all the momenta of all the several parts; and consequently

quently the momenta of all the several parts of a pendulum seem to be concentrated in this point—We may therefore call this point the center of momentum—It is usually called the center of oscillation—The center of percussion identical with the center of momentum.

Method of finding the center of momentum in a pendulum of known form and weight.

The length of a pendulum is the distance between the point of suspension and the center of momentum.

If the center of momentum be made the point of suspension, the point of suspension becomes the center of momentum reciprocally.

The general principles of dydamics illustrated by the simple machines called the mechanical powers, and by compound machines; in all of which, when the weight and power are in equilibrio, the momentum of the power equals the momentum of the weight; and to raise the weight as much more additional power must be applied as will be sufficient to overcome the resistance of the machine—The chief resistance in machinery is friction—Practical rules concerning machinery.

All that has been advanced concerning the compound motion resulting from the conjunct action of two momentary impulses, is also applicable to the compound motion resulting from two forces constantly acting.

2d, When one of the two forces is a momentary impulse, and the other a force constantly acting, the body moves in a curve, the nature of which curve varies according to the direction of the constant force.

Two cases of this compound motion considered: All other cases are matters more of curiosity than utility, and may be reduced to one or other of the two following.

a. When the constant force acts in a direction parallel to itself, the curve in which the body moves is a parabola. We have examples of this motion in bodies thrown or projected near the surface of the earth.

The dynamical principles of projectiles applied to artillery, or the art of gunnery.

b. When the constant force acts towards a fixed point, the curve in which the body moves is a

recurrent curve, or a curve which returns into itself.

The constant force tending to a fixed point is called the centripetal force ; the momentary impulse is called the centrifugal force ; the point to which the constant force tends is called the center of force. The curve in which the body moves is called the orbit ; the time which the body takes to pass over the whole orbit, *i. e.* the interval of time elapsed from the departure of the body from any certain point in the orbit till its return to the same point, is called the revolution, or period, or periodical time.

In the case of bodies moving in circular orbits, if P = the periodical time, s = the space which the body would move through by the action of the centripetal force F in any time t , $c = 3.1416$, and R = radius of the circle, we have the following propositions.

$$1st, P = ct \sqrt{\frac{2R}{s}}$$

$$2d, P = \frac{\sqrt{R}}{\sqrt{F}}$$

$$3d, F = \frac{R}{P^2}$$

4th, If the centripetal force be reciprocally as the square of the distance, $P^2 \div R^2$.

In the case of a body moving in any other curve than a circle;

1st, The areas, described by radii from the center of force to the moving body, the times of description.

2d, $F \div$ cube of the perpendicular from the center of force to the tangent.

3d, If the body move in an ellipse, and $D =$ the distance of the body from the center of force placed in one focus of the ellipse, then F is reciprocally $\div D^2$.

4th, The squares of the periods \div cubes of the mean distances.

If a body be acted on by two or more different centripetal forces, tending to two or more different centers, by the composition and resolution of forces, we can find the direction and quantity of one force equivalent to all these different forces, so that all cases, where there are several different centripetal forces, may be reduced to the case of a body moved by a single impulse, and one centripetal force.

We

We have examples of this kind of motion in the heavenly bodies.

That branch of Natural Philosophy which contemplates the heavenly bodies, and explains the phenomena and motions observable among them, is called Astronomy.

The heavens appear to be a concave hemisphere whose center is the observer's eye, and the earth's surface appears to be an extended plane which meets the concave in a circle, called the horizon.

In this concave are innumerable luminous bodies, some of which are stationary, called fixed stars, and others moveable, called planets. Two of these luminous bodies, more remarkable than any of the rest, are called the sun and moon.

The fixed stars ought first to be treated of, because they are fixed points to which we refer the places of the planets, and fixed marks by which we measure their motions.

Various opinions of Philosophers about the fixed stars—How the fixed stars may be distinguished from one another—Necessity for making catalogues,

catalogues, and constructing maps of them—The most noted catalogues and maps described and explained.

The sphere of the heavens seems to revolve once $23^{\text{h}}. 56^{\text{m}}. 4^{\text{s}}$.—Poles.

All the stars describe circles which are parallel to each other, and of which one is the greatest, viz. that which is in the middle between the two poles, and which is called the equator—Some of the stars are always above the horizon ; others go below the horizon in the west, and come up again above the horizon in the east ; rise, culminate, and set—The division of the horizon into four cardinal points, and these subdivided.

Meridian, where all the stars culminate, is a circle perpendicular to the horizon and to the equator ; passes through the south point of the horizon, the vertex or zenith, the poles, the north point of the horizon, and the nadir.

Of the elevation of the pole, and how to find it—Different in different places.

Different methods of finding the position of a meridian line.

Every particular fixed star culminates at the same

same altitude—The sun does not—Tropics—Tropical year $365^d. 5^h. 48^m. 48^s.$ —Distance between the tropics measured by the antients 250 years before Christ, and found to be $\frac{1}{3}$ of the whole circle, *i. e.* $47^{\circ}. 42'. 4''$.—Found in the year 1800 after Christ to be $46^{\circ}. 55'. 52''$.—Hence this distance seems to be diminishing.

The sun's diurnal revolution slower than that of the fixed stars, being about $24^h.$ varying $30^s.$ more or less, from $24^h.$ —The cause of this is a proper motion of the sun from west to east, making a complete revolution round the sphere among the fixed stars in $365^d. 6^h. 9^m. 11^s.$ called the sidereal year, which is $20^m. 23^s.$ longer than the tropical year—Heliacal rising and setting of the stars.

The sun's annual path through the heavens can be traced, and is found to be a circle called the ecliptic—The ecliptic crosses the equator in two opposite points called the equinoxes—Obliquity of these two circles to each other—The equator sometimes called the equinoctial line, and the tropics some times called solstices.

Other imaginary great circles of the sphere
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are two colures, circles of declination or meridians, circles of latitude, and vertical or azimuth circles.

The imaginary lesser circles are, *1st*, Parallels to the equator, or parallels of declination, of which, four are distinguished by proper names, viz. the two tropical and two polar circles; *2dly*, Parallels to the ecliptic or parallels of latitude; and, *3dly*, Parallels to the horizon, or almacanors.

Uses of all these imaginary circles—Right ascension and declination, longitude and latitude—Altitude and azimuth, amplitude, oblique ascension and descension.

Moon's diurnal revolution—Phases—Lunation 29^{d.} 12^{h.} 44^{m.} 3^{s.}

Moon's proper motion among the fixed stars from west to east—Lunar period 27^{d.} 7^{h.} 43^{m.} 11¹₂^{s.}—Her path an apparent circle inclined to the ecliptic—Nodes—The inclination of the moon's path to the ecliptic and the place of the nodes vary—These variations irregular, but, on the whole, the place of the nodes moves retrograde.

A singular phenomenon sometimes happens at the time of the new moon, viz. an eclipse of the sun, which is to be more fully treated of in the sequel—Inferences from this phenomenon, 1st, The moon is a solid sphere; 2^d, The moon is between the sun and the earth; 3^d, The moon is not luminous in itself.

A similar phenomenon is sometimes observable at the time of the full moon, viz. an eclipse of the moon—Inferences from this phenomenon, 1st, The earth has a shadow; 2^d, The moon is enlightened by the sun; 3^d, The earth is a sphere.

The earth being ascertained to be a sphere whose center was identical with the center of the sphere of the heavens, all the imaginary points and circles of the heavens were referred to the surface of the globe of the earth—Hence all the circles of the sphere have their common center at the center of the earth—Difficulty about the horizon—Real and apparent horizon—Parallaxes—Uses of the imaginary circles on the surface of the globe of the earth.

All the phenomena relating to the diurnal motion

tion of the sphere from east to west are explicable on the supposition that the earth has a rotation on its axes from west to east in $23^{\text{h}}. 56^{\text{m}}. 4^{\text{s}}$.

Spherical problems—Different methods of solving them, *1st*, Mechanically, *2^d*, Instrumentally, *3^d*, Arithmetically.

The sun's motion in the ecliptic more particularly considered—The difference between the tropical (called also the equinoctial) year, and the sidereal year is owing to the precession of the equinoxes—The different methods by which this slow motion of the equinoxes may be ascertained—Its quantity is $50''.227$ annually.

The effects of the precession in altering the longitudes, right ascensions and declinations of the fixed stars, but not their latitudes, and in altering the situation of the pole of the sphere with respect to the fixed stars.

The sun's motion in the ecliptic from west to east not equable; being about the end of June, $57'. 16''$ in a day, and, about the end of December, $61'. 10''$ in a day.

The sun's apparent diameter also varies, being

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the least, viz. $31'.$ $31''$. when his motion is the slowest, and greatest, viz. $32'.$ $35''$. 58 , when his motion is the quickest.

Inference drawn from these two phenomena conjointly taken, that the sun is at different distances from the earth at different times, viz. farther from the earth when his motion is the slowest and his apparent diameter the least, and nearer the earth when his motion is quickest and his apparent diameter greatest.

Different hypotheses for explaining these phenomena; *1st*, By supposing the sun to move in an eccentric circle; eccentricity, apsides, apogeeum, perigeum, anomaly mean and true, prosthapheresis or equation; *2dly*, By supposing the sun to move in an epicycle; *3dly*, By supposing the sun to move in an ellipse—The last hypothesis found to be very nearly true, *i. e.* found to explain the phenomena very nearly.

The motion of the heavenly bodies used as a measure of time—The nature of time; time can only be measured by uniform motion; sidereal time; solar or apparent time; mean time; equation of time.

A year, a proper integral standard, and determined by the revolution of the sun in his orbit—Solar year and civil year.

Lunation used as a measure of time; months and weeks—Lunar year.

Difficulties of adjusting the civil year either with the solar or lunar year—Julian year; Julian calendar; its defects; was reformed by Pope Gregory; Gregorian calendar; epacts, and their use in finding the mean new and full moons—Metonic and other cycles.

Of the planets; only five, viz. Mercury, Venus, Mars, Jupiter, and Saturn, were known before the year 1782, when a sixth was discovered by Dr Herschell, and is called by the name of the discoverer.

Motion of the planets among the fixed stars very irregular and unequal—Sometimes they move from west to east, or directly, as do the sun and moon; sometimes from east to west, or retrogradely; sometimes they move neither directly nor retrogradely, but seem to stand still, when they are said to be stationary.

None of them ever recedes far from the ecliptic; most of them only a few degrees; and none of

of them more than 10° .—Zodiac is a belt in the heavens bounded by two parallels of latitude, one on each side of, and 10° distant from, the ecliptic.

The paths of the planets cross the ecliptic in two opposite points called the nodes, each planet's path having its own peculiar nodes.

Peculiarities in the motions of Mercury and Venus which are not observable in the other four—*1st*, They never recede far from the sun—Elongation—*2d*, Sometimes they are seen to pass over the sun—Transit—*3d*, Always move retrogradely during a transit.

Peculiarities observable in the motions of the other four planets—*1st*, They are seen at all distances from the sun—*2d*, When opposite to the sun, they always move retrogradely—*3d*, When near the sun, they always move directly; and, at that time, their motions are the quickest.

Several different hypotheses or systems have been contrived for explaining the apparent motions of the planets—*1st*, The Ptolemaic, which is extremely defective—*2d*, The Egyptian, which fully explains the motions and phenomena of

Mercury

Mercury and Venus, but not of the other four.
3d, The Thyconic, which fully explains all the motions and phenomena of the planets, but it is very complex. 4th, The Copernican, which fully explains all the motions and phenomena of the planets, and is much more simple than the Thyconic.

Objections against the Copernican system refuted, and the reasons why we adopt it as the true system—Heliocentric and geocentric places of the planets; annual parallaxes.

The planets revolve each in an ellipse round the sun, which is placed in one focus common to all the seven ellipses—Excentricities, apsides, periods, apheliums, periheliums.

Various methods of ascertaining all the particulars of a planet's motions, and the form and situation of its orbit, by actual observation.

The motion of the earth in its orbit more particularly considered—Seasons of the year.

Motion of the moon more particularly considered; whence we conclude, that the moon moves in an ellipse round the earth placed in one focus, and describes areas proportional to the times.

Hence

Hence its motion is a compound motion resulting from a momentary impulse and a centripetal force—The centripetal force of the moon proved to be identical with the force of gravitation.

Jupiter has four moons revolving round him at different distances—The periods and distances of these moons ascertained from observation; whence it appears, that the squares of their periods \div cubes of the distances.

Saturn has seven moons, and Herschell's planet six moons, all of which move round their primary planet at different distances, observing the same law, viz. that the squares of their periods \div cubes of their distances.

Rotation of the planets on their axes, and the situation of their axes with respect to the planes of their orbits, discoverable by observing spots or inequalities on their surfaces—Peculiar phenomena of the belts of Jupiter and the ring of Saturn.

In consequence of the rotation of the planets on their axes, they are not perfect spheres, but oblate spheroids—The figure of the earth briefly noticed—The effect of this spheroidal figure on the parallaxes, especially on the parallax of the moon.

Eclipses

Eclipses of the moon and sun more particularly described—Methods of predicting them explained and exemplified.

Other eclipses; occultations and transits—The great uses of all these phenomena in chronology, geography, navigation, and astronomy.

Comets; different opinions about them—Like the planets, they revolve in ellipses round the sun in one focus.

By observation, all the planets and comets revolve round the sun in ellipses, describing areas \propto times; the squares of their periods \propto cubes of their mean distances; the secondary planets observe the same law in revolving round their respective primaries: Their motion is therefore a compound motion, produced by a momentary impulse and a centripetal force; and since the centripetal force of the moon has been demonstrated to be identical with the force of gravitation, we conclude the centripetal forces of all the other secondary planets, and also of the primary planets and comets, to be the same, namely, gravitation.

The general conclusions are,

1st, That the world had a beginning; namely, when the momentary impulse was first given.

2d, That it is held in existence by a constantly acting force or power.

3d, That it must cease whenever this power is withdrawn.

4th, That the whole system is the consequence of design, in which there is a display of wisdom and power far exceeding the utmost stretch of human thought.

The system, however, must be examined still farther. The sun, which is the center of the system, is the source of all the light and heat which we enjoy. Light and heat must therefore be inquired into.

That branch of Natural Philosophy which treats of the nature of vision, is called optics; but as there can be no vision without light, it is usual to treat of the nature and properties of light in this branch.

Light is most probably a body; and it moves naturally always in straight lines.

The motion of light proved by observations on
the

the eclipses of Jupiter's Satellites ; and its velocity thence ascertained to be very great, viz. $16\frac{1}{4}$ minutes in traversing the longer axis of the earth's orbit.

Definitions of a ray ; a beam ; pencil, converging or diverging ; medium.

If a ray of light fall on any surface, it is turned out of its ordinary straight course in two ways.

1st, If the surface be not disposed to let the light pass through it, the ray is reflected.

2^d, If the surface be the surface of a perfectly transparent medium, the ray passes through the medium, after having been bent or refracted at the surface.

If the surface be the surface of an imperfectly transparent medium, part of the ray is reflected, and the other part is refracted at the surface.

Definitions—Incident ray ; incident point ; reflected ray ; refracted ray ; angle of incidence ; angle of reflection ; angle of refraction.

General law of reflection—The angle of reflection equals the angle of incidence.

General laws of refraction.

1st, If the ray passes out of a rare into a den-

fer medium, it is refracted towards the perpendicular.

2d, If the ray passes out of a dense into a rarer medium, it is refracted from the perpendicular.

3d, In any two media, the sine of the angle of refraction \neq sine of the angle of incidence.

4th, Different media have different refracting powers ; thus, if the medium out of which the ray passes be air, and the medium into which it passes be water, then the sine of the angle of incidence : sine of the angle of refraction :: 4 : 3. Out of air into glass :: 31 : 20, or 3 : 2. Out of air into diamond :: 12 : 5.

No law yet discovered respecting the different refractive powers of different media ; these powers are therefore to be ascertained by experiment.

5th, If a ray of light fall perpendicularly on the surface of a refracting medium, it will not be refracted.

6th, No ray passing out of a dense into a rarer medium can be refracted, if the angle of incidence be greater than a certain limit, which limit varies for different media : And, if the angle of incidence be greater than this limit, no part of the

the ray will be refracted, but the whole of it will be reflected.

7th, A ray, after refraction, is divided into seven differently coloured rays ; viz. red, orange, yellow, green, blue, indigo, and violet, forming an oblong image. Different degrees of refrangibility in the differently coloured parts of the original ray ; the violet being most refracted, and the red the least. Ratios of the sines of the angles of incidence to the sines of the angles of refraction for each.

Luminous objects are seen by their own or native light. Opake objects seen by light being reflected from them ; and objects appear to be of different colours because they are disposed to reflect or transmit only some peculiar parts of light, *i. e.* only some peculiar colour.

The rays of light issuing from, or reflected from every point of an object, carry with them the image of that point. And all the images of all the different points of an object may be collected so as to form a complete image of the whole object—Peculiar circumstances of this phe-

nomenon—

nomenon—Difference between distinctness and brightness of an image or of an object.

If parallel rays be reflected or refracted by one plane surface, or by several plane surfaces that are parallel to each other, they will remain parallel after the reflection or refraction.

If parallel rays be reflected or refracted by two or more plane surfaces not parallel to each other, they will not remain parallel after the refraction or reflection, but will be either diverging or converging.

Parallel rays, after reflection or refraction, by a curved surface, become, in some instances, diverging, and in others converging, according to the nature of the curved surface.

Focus is a point in which converging rays meet, or from which diverging rays seem to diverge, after reflection or refraction—Distinction between principal focus, conjugate focus, and virtual focus.

Parallel rays reflected to a focus by a parabolical concave surface.

Diverging rays reflected to a focus by an elliptical concave surface, the two foci of the ellipse being the conjugate foci.

Any

Any other concave curved surface than the two above mentioned, reflect rays so as to make them cross each other in many different points, so that a great number of imperfect foci are formed : These imperfect foci are arranged in a curve called the catacaustic curve, which varies according to the nature of the reflecting curved surface.

Since a small portion of a spherical surface nearly coincides with a parabolical and with an elliptical surface, small portions of spherical surfaces may be, and commonly are, used instead of either parabolical or elliptical surfaces.

Mirrors are either plane, or convex spherical, or concave spherical surfaces.

In a plane mirror, the focus is virtual.

In a convex spherical mirror, the focus is also virtual.

In a concave spherical mirror, the focus is real, being sometimes principal, and sometimes conjugate.

To find the focus in plane mirror.

To find the focus in a spherically convex or concave mirror. $1/f$, Mathematically. $2d$, Mechanically.

Curved

Curved surfaces of a peculiar kind refract parallel or diverging rays to a focus ; but as these peculiar curved surfaces are difficult to form by art, and as small portions of spherical surfaces refract parallel and diverging rays nearly to a focus, these last are generally used in practice.

Focus by a convex spherical surface, sometimes virtual, principal, or conjugate.

Focus by a concave spherical surface, always virtual.

Lenses, different species of them : Axis of a lens : Vertex : Curvature : Diameter or aperture.

Problems for determining the focus in every different species of lens. *1st*, Mathematically. *2d*, Mechanically.

Of images formed in the foci of mirrors and lenses.

Of distorted images.

Image of the object formed on the retina is the cause of vision.

The structure of the eye exhibited by dissection, and explained.

Of

Of the nature of vision—Perfect or distinct vision—Imperfect or indistinct vision depends on several different circumstances—The imperfections known by the names of short-sightedness and long-sightedness particularly considered, and the methods of remedying these imperfections—Illusions in vision.

Of vision by glasses—Optical illusions—Optical instruments ; viz. Camera obscura ; different construction of this instrument for different purposes—Reading glasses—Microscopes, single, double, solar, reflecting—Telescopes ; refracting telescopes of different kinds ; reflecting telescopes of different kinds : Of the imperfections of telescopes, and how these imperfections may, in some measure, be obviated—Hadley's instrument for measuring angles by means of two reflecting plane mirrors ; the great utility of this instrument ; practical directions for adjusting it, and how to use it—Various other optical instruments.

When rays of light fall on any surface, and are neither reflected nor refracted, but are absorbed, then heat is produced.

Various

Various opinions about the nature of heat ; but chiefly,

1st, Lord Bacon's opinion, (which was adopted by Mr Boyle, Sir Isaac Newton, and others,) that heat consists in a motion among the parts of the heated body—The grounds of this opinion.

2d, Professor Rickman's opinion, that heat is a body sui generis—The grounds of this opinion.

The most obvious property of heat is its disposition to diffuse itself equally through all substances whatsoever—Equilibrium of heat, or rather equilibrium of temperature.

Of the equal distribution of heat through fluids, and the impossibility of heating one part of a fluid mass more than any other part of the same mass.

Of the unequal distribution of heat through the atmosphere—Several phenomena explained.

The general effects of heat are,

1st, Expansion—The general laws of expansion by heat not yet ascertained—Inconveniences of expansion on several occasions, and how these inconveniences may be, in some cases, obviated—Uses to which expansion may be applied—Thermometers—The history of their invention—Description

scription of the method of constructing thermometers, and adapting scales to them; different scales described and explained, viz. Fahrenheit's, Reaumur's, &c.—Different kinds of thermometers for different purposes—Exceptions to expansion, viz. that some few substances contract by being heated, and expand by being cooled—Several phenomena explained by means of the principles above delivered.

2d, Fluidity—Definition of a fluid—All solids become fluid by being heated—The phenomena, observable when a solid is changed into a fluid by means of heat, are, 1st, The change is slow; 2^d, The temperature of the mass is always the same during the whole time of the change; 3^d, Different substances require very different degrees of heat to change them from a solid to a fluid state.

Former opinions respecting the nature and cause of fluidity—The hypothesis of Professor Muschenbrook, concerning frigorific particles, examined and refuted—The doctrine of latent heat explained and examined—This doctrine proceeds on the supposition that heat is a material

F substance;

substance ; doubts whether heat be really a substance *sui generis*—The doctrine of latent heat does not explain all the phenomena observable in the melting and congealing of bodies—Explanation of the phenomena on the supposition that heat is a condition of the heated body, and consists in a motion among the particles of matter composing the body—This doctrine of fluidity explains many phenomena concerning the melting and congealing of bodies which the doctrine of latent heat does not.

3d, Evaporation—Definition of vapour—Phenomena attending the conversion of a body into vapour similar to those attending the conversion of a solid into a fluid—*1st*, The conversion is slow—*2dly*, The temperature of the mass is always the same during the whole time of the conversion—*3dly*, Different substances require very different temperatures for their conversion into vapour.

Former opinions respecting the formation of vapour—The doctrine of latent heat insufficient for explaining all the phenomena—Explanation of all the phenomena on the supposition that heat consists in a motion among the particles of matter composing the body.

Farther

Farther considerations respecting the different states or forms in which a substance exists, viz. in a solid state, in the state of a fluid, and in the state of vapour. Most substances, by the application of heat, pass through the intermediate state of fluidity before they are converted into vapour; and the very few substances which do not, may be made to do so by proper management—This phenomenon inexplicable by the doctrine of latent heat; but fully explicable on the supposition that heat consists in a motion among the particles of matter composing the body.

4th, Ignition—The connection between light and heat.

5th, Inflammation—This effect of heat is confined to a certain class of substances called inflammable substances—No inflammation can take place without the action of the air—Farther considerations respecting inflammation reserved till we have treated of air.

* * *

More particular consideration of fluidity—That branch of Natural Philosophy which considers

siders and treats of the nature and general properties of fluids is called Hydrostatics.

Hydraulics is the art of raising and conveying fluids ; and this art is founded on the principles which the science of hydrostatics teaches.

The surface of a fluid at rest is a plane parallel to the horizon ; but if the surface be very extensive, then it is spherical.

The surface of a fluid stands at the same horizontal height or level in vessels that communicate by pipes or channels—This property of fluids applied to many useful purposes ; levels, artificial horizon, conducting water into towns, &c.

If a fluid be at rest in a vessel, whose base is parallel to the horizon, then equal parts of the base are equally pressed by the fluid.

The pressure of a fluid at any depth is proportional to the depth, and is equal in all manner of directions.

The pressure of a fluid on the horizontal base of the containing vessel \div the base (when the depth of the fluid is the same) whatever be the shape of the vessel.

And

And universally the pressure \div depth of the fluid, and the base of the containing vessel conjointly.

Of spouting fluids—The path described by a spouting fluid is a parabola, except when spouting perpendicularly. A fluid spouting perpendicularly upwards rises nearly as high as the surface of the fluid in the reservoir.

The velocities of spouting fluids \div square roots of the depths of the aperture below the surface.

The quantities discharged \div square roots of the depths.

The quantity discharged \div the area of the aperture; and if the aperture be circular \div square of the diameter of the aperture.

And universally, the quantity discharged \div square root of the depth and the area of the aperture conjointly.

If d = the depth of the aperture below the surface, b = the diameter of the circular aperture, both in inches, then the absolute quantity discharged in a second of time = $0.7854 b^2 \sqrt{386 d}$. cubic inches, or = $4 b^2 \sqrt{d}$. gallons English wine measure.

The

The same principles applied for ascertaining the quantity of a fluid that flows through a slit of known dimensions, in the side of a full vessel.

Application of the two last propositions to the practice of measuring the quantity of water discharged by a spring, or the efflux of a mill-dam, or other stream.

If a fluid runs through a pipe, the velocities in different parts of the pipe \asymp transverse sections of the pipe in these parts reciprocally ; and if the pipe be cylindrical \asymp squares of the diameters reciprocally.

The quantities of a fluid running with the same velocity through cylindrical pipes of different diameters \asymp squares of the diameters.

Of the motion of fluids in channels, rivers, mill-leads, &c.

The figure of a fluid globe at rest is perfectly spherical ; but if the fluid globe has a rotation on an axis, then the perfect sphere is changed into an oblate spheroid.

Investigation of the ratio of the polar and equatorial radius of the earth, according to the dynamical

mical principles formerly delivered. This ratio ascertained to be 229 : 230.

Other methods of finding the equatorial and polar radii of the earth, by pendulums, or the going of pendulum clocks, and by actual measurement; whence

The equatorial radius = 20993530 feet.

The polar radius = 20895806.

The mean radius = 20944668.

The disturbance of the oblate spheroidal figure of a rotatory fluid globe, by the attractive forces of other bodies.

The phenomena of the tides explained by the principles established in the foregoing proposition.

When a solid body is immersed in a fluid, it displaces a quantity of the fluid equal to its own bulk.

If the solid is capable of sinking in the fluid, it loses a part of its weight by being immersed in the fluid.

The loss of weight which the solid sustains is equal to the weight of a quantity of the fluid of the same bulk with the immersed solid.

This

This property of bodies immersed in fluids applied to the purpose of ascertaining the specific gravities of bodies.

Of the construction of tables of the specific gravities of bodies ; and why pure water is assumed as the general standard in these tables.

Different methods of finding the specific gravities of solid bodies.

1*t*, If the solid be heavier than water.

2*d*, If the solid be lighter than water.

3*d*, If the solid be liable to be dissolved by water.

Different methods of finding the specific gravities of bodies in the form of powder, as sand, earth, &c.

Different methods of finding the specific gravities of fluids.

Utility of the tables of specific gravities of bodies.

Several problems solved by the principles derived from the doctrine of specific gravities.

Of floating bodies—They displace a quantity of fluid equal to their own weight—Floating bodies applied to ascertain the specific gravity of bodies

dies, either solid or fluid; to weigh cargoes of boats and ships.

On the equilibrium of floating bodies.

The center of gravity of the whole floating body, and the center of gravity of the immersed part of the floating body, are always in the same perpendicular line to the horizon.

The equilibrium can only be permanent when the distance between these two centers of gravity is the least possible.

Practical rules concerning the form of bodies intended to float.

A more particular consideration of vapours, or elastic fluids.

That branch of Natural Philosophy which treats of the nature and general properties of elastic fluids, is called pneumatics.

The most abundant elastic fluid in nature is the air in which we live, and which, surrounding the globe of the earth, forms the atmosphere.

Air is heavy—Is capable of being weighed—Its specific gravity is 0.001222, that of pure water being unity.

G

The

The air capable of being taken out of a vessel by several means; but most conveniently by means of an instrument called an air-pump.

This instrument described, and its construction exhibited and explained. Its imperfections. It can never make a perfect vacuum, but only approximates to a vacuum.

The elasticity of the air considered, and proved by many experiments.

The pressure of the atmosphere very great—Method of ascertaining the quantity of this pressure, which is found to be between 14 and 15 pounds avoirdupoize weight on every square inch of surface—The atmosphere, like all other fluids, presses equally in all manner of directions.

The barometer, which shews and measures the weight or pressure of the atmosphere, is a useful instrument—Different constructions of this instrument, with their respective advantages and defects.

The pressure of the atmosphere is not always the same, and seems to have some sort of connection with the state of the weather, and hence the barometer is a weather-glass.

Practical directions for judging of the state of the weather by the rising and falling of the quicksilver in the barometer.

The density of the air varies as the pressure varies ; hence the density \div the weight of all the superincumbent air.

Hence also the density of the air is different at different heights from the surface of the earth.

The logarithm of the density \div height above the surface of the earth.

The density of the air reciprocally \div the heat or temperature.

Hence universally the density \div pressure directly, and the temperature reciprocally.

The pressure is measured by the barometer, and the temperature is measured by the thermometer. Hence by these two instruments we can measure the density ; and hence also the barometer and thermometer are capable of being employed for measuring heights.

Practical directions for measuring heights by means of the barometer and thermometer.

Several phenomena explained which are caused by the pressure of the atmosphere.

The

The pressure of the atmosphere, being a very great force, is frequently applied to several useful purposes—The syphon and its manner of operation explained.

The principles of the common pump explained, and its construction considered—Forcing, lifting, and other pumps—Water engines.

The fire engine described, and its general principles explained—History of the various improvements which this useful machine has received.

* * *

History of the discovery made by Mr Boyle, that air is sometimes found combined with other substances ; in which state it is void of elasticity, and was called fixed air. Dr Hales first observed fixed air to be different from the air of the atmosphere.

Fixed air can be separated from the substances which contain it, and, when separated, it always recovers its elasticity.

It may be separated from the substances which contain it. *1st*, By removing the pressure of the atmosphere. *2dly*, By the application of heat.

3dly,

3d, By mixing the substance containing it with other substances.

The first method is practicable only in a very few cases—Examples.

By the second method, the fixed air is most commonly separated suddenly; and, with violence, producing explosions—Examples.

By the third method, the air is separated, except in a few cases, gradually—Examples.

On the general nature of mixture, and the phenomena observable when substances are mixed with each other.

Elective attractions considered.

Air extricated from chalk by mixing the chalk with an acid.

When this air is examined, it is found to have many properties by which it differs from common or atmospheric air—1st, It is heavier than atmospheric air—2^{dly}, It extinguishes flame immersed in it—3^{dly}, It kills animals that breath it—4^{thly}, It unites with water, imparting to the water an acid taste and a peculiar briskness,

Natural history of this air—It occurs frequently in a separate state; is contained in various other

other substances besides chalk; is extricated or produced by several natural operations—Its various names.

Another peculiar kind of air extracted from water, by mixing the water with a metal and the acid of sulphur—The general properties of this air—Its natural history and various denominations.

Another peculiar kind of air, called nitrous air, extracted from nitrous acid, by mixing the acid with a metal—The properties of this air are, *1st*, It is noxious to animals—*2d*, It extinguishes flame—*3d*, When mixed with four times its bulk of atmospheric air, red fumes are produced, which, being condensed, are found to be nitrous acid; the five bulks of air are reduced to three; and the air thus lessened is unfit for the support of animal life, or of combustion, and has hence been called Azot.

If animals breath in a portion of confined atmospheric air, the animals die, and the bulk of the air is reduced to about three-fourths of its original bulk, the remainder being azot, or the same kind of air as that which is obtained by mixing

mixing atmospheric air with a certain portion of nitrous air.

Inflammable substances burning in confined atmospheric air produce the same effect.

The conclusion drawn from these phenomena is that the atmosphere consists of two distinct kinds of air; the one of which, being about the fourth part of the whole, is employed for the support of animal life and of combustion, and that the other three-fourths is unfit for these purposes—The first has therefore been called vital air, empyreal air, or pure air, and the other azotic air or simply azot.

Another conclusion drawn from these phenomena is, that the nitrous acid is a compound consisting of pure air and nitrous air.

Pure air separated from nitre—Its properties more particularly considered, and the contents of the atmosphere determined to be,

Vital or pure air, - - -	27 parts	in the
Azotic air, - - -	72 parts	
Chalk air, - - -	1 part	

When inflammable substances are burnt in pure air, all the air disappears; and, if the com-

bustion

buſtioη be fo managed that nothing escapes, we find the produce to be equal in weight to the sum of the weights of the inflammable ſubſtance and of the air: And ſince, in moſt caſes, the produce, after combustion, is an acid, pure air has been called oxygene.

Farther conſideration of the union of pure air with other ſubſtances.

Pure air being neceſſary for ſupporting animal life and combustion, a great quantity of it is con-tinually expended in theſe natural proceſſes; hence all of it would in a ſhort time be conſum-ed, had not nature provided means for reproduc-ing it—The diſtinct proceſſes of Nature by which this reproduction of vital air is effected—General inference that there is a diſplay of wi-dom, deſign, and conſtrivance, for continuing and preſerving the world in its preſent ſtate.

* * *

Besides the uſes of air, above enumerated, we find it to be the cauſe of ſound.

Sound is produced on the following occasions, *i/ſt*, When air rufhes violently into a vacuum—

2d,

2d, When condensed air rushes violently out of its confinement—3d, When a solid is quickly moved through the air—4th, When air passes quickly through a parcel of solids, or through holes—5th, When solid elastic bodies are struck against one another in air. Air, therefore, is always necessary.

Cause of sound more particularly considered.

Velocity of sound 1142 feet in a second.

Echoes, simple and multiplied.

Sounds vary in tone, and are either grave or acute; a grave tone from slow vibrations, an acute tone from quick vibrations.

Of the nature of the vibrations of a musical string.

The number of vibrations in strings of the same materials and diameter \propto square root of the tension with which they are stretched.

The number of vibrations in strings of the same materials and diameter \propto lengths reciprocally.

And universally, the number of vibrations \propto square root of the tension directly, and the length of the string reciprocally.

Of concords, discords, and harmony.

Of currents in the atmosphere, commonly called winds.

They are either, *1st*, perennial or constant winds, as the trade winds between the tropics. Or, *2dly*, periodical or stated winds, as the monsoons, in large bays and gulfs. Or, *3dly*, variable winds,

Of the general cause of winds; how this cause is so modified as to produce all the effects above mentioned.

Whirlwinds considered, and their cause explained.

Rain; its formation—Mists, dews, and clouds.

Various phenomena accompanying mists and rain—Rainbow, weathergalls, halos, parhelia, &c.

Of atmospherical refractions.

Of the resistance which the air and other fluids make against bodies moving in them.

Resistance \propto square of the velocity of the moving body.

Resistance

Resistance \doteq square of the diameter of the moving body.

Resistance \doteq density of the fluid in which the body moves. This last proposition supposes the fluid to be perfect, *i. e.* whose particles of matter have no attraction of cohesion, or a fluid which has no tenacity.

Universally, the resistance \doteq square of the velocity, square of the diameter of the moving body, and the density of the fluid conjointly.

In the case of falling bodies, when they have acquired a certain velocity, the resistance becomes equal to the accelerating force, and the body falls, not with an accelerated, but with an uniform velocity.

What relates to the resistance which bodies meet with when they move in fluids holds good with respect to the resistance which a body at rest exerts against a moving fluid; or to the force which a moving fluid exerts on a body at rest.

These principles applied for ascertaining the action of a stream of water against piers and bulwarks, and also against the float-boards of mill-wheels, &c.

The

The action of the wind against buildings, and against the sails of wind-mills and the sails of ships.

The above principles applied to the failing of ships.

Peculiar attractions.

1/2, The attraction of the magnet for iron and for other magnets.

Two points in the magnet which attract more strongly than any other parts of the magnet.

A magnet communicates its powers to a piece of iron without having its own power in the least diminished. Hence artificial magnets.

On the directive quality of the magnet, and the peculiarities of this quality. Poles of the magnet.

On the peculiarities relating to the action of magnets on one another.

Iron and steel made magnetical without the intervention of a natural magnet.

The various uses of the magnet—Of the manu-

rines

riners compass; practical remarks on its construction; directions relative to its use and management.

Various opinions about the nature of magnetism enumerated and examined—All of them hypothetical and insufficient for explaining the phenomena.

2d, The attraction of amber, and of other substances peculiarly circumstanced, for a variety of other substances.

Electricity—General phenomena exhibited.

Proofs of the existence of the electrical matter—The mode of its passing from one body to another

Of what is called positive and negative electricity.

Of the similarity between electricity and thunder.

The phenomena of thunder and lightning described and explained. Thunder proved to be identical with electricity.

The phenomena of the aurora borealis considered. Of the connection mutually existing between

tween the aurora borealis, electricity, and magnetism.

Practical directions for obviating the effects often produced by lightning.

Conclusion, containing general remarks on the constitution of the world, the wisdom displayed in its formation, and in the contrivances for its preservation.

F I N I S.

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